Columbia University in the City of New York | New York, N.Y. 10027

OFFICE OF PROJECTS AND GRANTS

Box 20 Low Memorial Library

Report on ONR Contract N00014-85-K-0583

TITLE: "TRANSFORM AND FRACTURE ZONE MORPHOLOGY" DATE: Sep. 1985
per Randy Jacobson ONR/425GG
TELECON 3/9/90 VG

Final Technical Report

AD-A219 017

Original Objectives

The broad objectives of the research sponsored by the Office of Naval Research under contract N00014-85-K-0583 were to increase our understanding of the fundamental tectonic and petrological processes which determine the genesis and evolution of the oceanic lithosphere. In order to achieve these objectives, our research has been focused on the two main types of plate boundaries found in the ocean basins: (a) accretionary boundaries along mid-ocean ridges, and (b) transform boundaries. Both themes have been approached in two areas: (a) the central and northern Red Sea, where the earliest stages of development of an oceanic accretionary plate boundary and transform boundaries can be observed; (b) the equatorial Mid-Atlantic Ridge, where a mature system of short spreading ridge axis segments are offset by some of the largest active transforms of the entire mid-ocean ridge system. We have attempted in our research to combine as much as possible a morphotectonic with a geochemical/petrological approach, in order to achieve broader answers to our objectives.

Military Publications, Periodical

Work Accomplished

Red Sea Program - Two cruises were carried out in the central and northern Red Sea, one in 1979, one in 1983. Both cruises were with Italian research vessels, with no ship-time costs for ONR. Bathymetry, seismic reflection profiling, magnetometry, heat flow, hard rock and sediment sampling were carried out during these two cruises. Field work on the island of Zabargad, a unique uplifted body of sub-Red Sea lithosphere, was also carried out. The data obtained in the field efforts were processed and interpreted at L-DGO, where geochemical-petrological work on the samples was also carried out.

Equatorial Atlantic - Our research program in the equatorial Atlantic was based on data obtained during ONR-sponsored expeditions conducted from University of Miami vessels while the present writer was at the Rosenstiel School of Marine and Atmospheric Sciences, and during an ONR-sponsored L-DGO expedition with the *R/V Conrad* (Cruise RC 21-04), which operated in the Vema F.Z. area (Atlantic, 10°-11°N). Bathymetric, seismic reflection and magnetometric data from these cruises were processed and interpreted at L-DGO, where the petrology of hard rock samples was also studied. A field program which included the submersible ALVIN has been carried out at the Oceanographer F.Z. (35°N in the Atlantic).

90 03 13 186

DTIC ELECTE MAR 13 1990 S B D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Results and Conclusions

The following is a brief summary of the main accomplishments of this research program. These accomplishments are reported in depth in the published papers resulting from this program, a list of which is appended to this report.

(1) It was established that the large transform/fracture zones offsetting slow-spreading ridges are the loci of intense vertical tectonic movements. These vertical tectonic motions are responsible for some of the roughest topography of the ocean basins, such as that observed in the equatorial Atlantic.

(2) Transfom-related vertical crustal motions have created islands which sank below sea level about 5 my ago at the Romanche F.Z. and about 3 my ago at the Vema F.Z. Subsidence rates were one order of magnitude faster than "normal" thermal subsidence of the crust of equivalent age.

(3) A petrological study of mantle-derived peridotitic rocks from the equatorial and northern Atlantic has established that the upper mantle in this region has ~100 km wavelength heterogeneities in composition and/or thermal structure. These regional variations of mantle properties are correlated with variations of gravimetry and geoid anomalies.

(4) The study of the axial troughs of the central Red Sea led us to a model of opening of a new ocean with initial emplacement of oceanic crust, not along a continuous fracture, but in equidistant nuclei caused perhaps by upwelling of asthenospheric diapirs related to Raleigh-Taylor-type instabilities. The axial propagation from the initial nuclei would cause the formation of the initial rift. This model can be applied not only to the Red Sea and Gulf of Aden, but also to the opening of the Atlantic in the Mesozoic.

(5) We have clarified the existence in the Red Sea of transverse fracture zones, probably inherited from pre-existing continental structures. These fracture zones are of great importance in determining the geometry of initial opening and in understanding the origin of large oceanic transform faults. One of these is the Zabargad Fracture Zone, which crosses the central Red Sea in a N20°E direction.

(6) We have shed light on the geochemical and structural features of a large peridotite body derived from the upper mantle and exposed on the island of Zabargad (Figure 2). The study of this peridotitic body allowed us to determine the properties of the mantle beneath the pre-oceanic rift, and to propose a hypothesis on the evolution of the upper mantle from a sub-continental to a sub-oceanic setting.

STATEMENT "A" per Randy Jacobson
ONR/4256G
TELECON 3/9/90 VG

n For
A&I
:ed
tion
per Telecon
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

(7) From the study of crustal units outcropping on Zabargad we have concluded that basic magmas are intruded at the base of continental crust before and during the early stages of crustal rifting. This study led us to suggest that the thermal anomaly in the mantle preceded the process of rifting in the Red Sea. Therefore, this work suggests a hypothesis of active rather than passive rifting of the Red Sea.

Published Papers Resulting Totally or Partially from this ONR Contract

Bonatti, E., M. Sarntheim, A. Boersma, M. Gorini and J. Honnorez, 1977, Neogene crustal emersion and subsidence at the Romanche fracture zone, equatorial Atlantic. Earth Planet. Sci. Lett., 35, 369-383.

Bonatti, E., K. Hartman, F. Innocenti and R. Kay, 1977. Basalt drilled from the Vema Fracture zone. Deep Sea Drilling Project, Initial Reports, 39, 507-511.

Bonatti, E., 1978. Vertical tectonism in oceanic fracture zones. Earth Planet. Sci. Lett., 37, 369-379.

Bonatti, E., 1978. Genesis of metal deposits in the oceanic lithosphere. Scientific American, 238, 54-61.

Bonatti, E. and P.R. Hamlyn, 1978. Mantle uplifted block in the western Indian Ocean. Science, 201, 249-251.

Bonatti, E., V. Kolla, W.T. Moore and C. Stern, 1979. Metallogenesis in marginal basins: Fe-rich basal deposits from the Philippine Sea. Marine Geology, 32, 21-37.

Bonatti, E., A. Chermak and J. Honnorez, 1979. Tectonic and igneous emplacement of crust in oceanic transform zones. 2nd Ewing Symposium Volume, AGU, 239-248.

Kolla, V., L. Nadler and E. Bonatti, 1980. Clay mineral distribution in surface sediments of the The Phillipine Sea. Oceanol. Acta, 3, 245-250.

Hamlyn, P.R. and E. Bonatti, 1980. Petrology of mantle-derived ultramafics from the Owen fracture zone, northwest Indian Ocean: implications for the nature of the oceanic upper mantle. Earth Planet. Sci. Lett., 48, 65-79.

Bonatti, E., J. Lawrence, P.R. Hamlyn and D. Breger, 1980. Aragonite from deep sea ultramafic rocks. Geochim. Cosmochim. Acta, 44, 1207-1214.

Bonatti, E. et al., (CNR Red Sea Cruise Staff), 1980. Geology of the Red Sea between 23° and 25°N: preliminary results. Accademie Nazionale Lincei, meeting on Geodynamic Evolution of the Afro-Arabian Rift System, 607-613.

Bonatti, E., and A. Cermak, 1981. Formerly emerging crustal blocks from the equatorial Atlantic. Tectonophysics, 72, 165-180.

Bonatti, E. and P.R. Hamlyn, 1981. Oceanic ultramafic rocks. The Oceanic Lithosphere, In: The Sea, C. Emiliani, Ed., vol. VII: Wiley, New York, 241-283.

Harrison, C.G.A. and E. Bonatti, 1981. The Oceanic Lithosphere. In: The Sea, C. Emiliani ed., vol. VII, Wiley, New York, 21-48.

Bonatti, E., 1981. Metal Deposits in the Oceanic Lithosphere. In: The Sea, C. Emiliani, Ed., vol. VII, Wiley, N.Y., p.639-686.

Bonatti, E., P.R. Hamlyn and G. Ottonello, 1981. The upper mantle beneath a young oceanic rift: peridotites from the island of Zabargad (Red Sea). Geology, 9, 474-479.

Bonatti, E., and K. Crane, 1982. Oscillatory spreading explanation of anomalously old uplifted crust near oceanic transforms. Nature, 300, 343-345.

Bonatti, E., R. Sartori and A. Boersma. 1983. Vertical crustal movements at the Vema fracture zone in the Atlantic: evidence from dredged limestones. Tectonophysics, 91, 213-232.

Bonatti, E., R. Clocchiatti, P. Colantoni, R. Gelmini, G. Marinelli, G. Ottonello, R. Santacroce, M. Taviani, A.A. Abdel-Meguid, H.S. Assaf and M.A. El Tahir 1983. Zabargad (St. John) Island: an uplifted fragment of sub-Red Sea lithosphere. Jour. Geol. Soc. London, 140, 667-690.

Bonatti, E., E.C. Simmons, D. Breger and P.R. Hamlyn. 1983. Ultramafic rocks/sea water interaction in the oceanic crust: Mg silicate (sepiolite) deposit from the Indian Ocean floor. Earth Planet. Sci. Lett., 62, 229-238.

Bonatti, E., 1983. Hydrothermal metal deposits from oceanic rifts: a classification in: "Hydrothermal Processes at Seafloor Spreading Centers" NATO Conference Series in Marine Sciences, Plenum Press. p. 491-502.

Bonatti, E., Colantoni, P., DellaVedova, B. and Taviani, M., 1984. Geology of the Red Sea Transitional Region, 22°N to 25°N. Oceanologica Acta., 7, 385-398.

Bonatti, E., Lawrence, J. and Morandi, N. 1984. Serpentinization of oceanic peridotites: Temperature dependence of minerology and boron content. Earth Planet. Sci. Lett., 70, 88-94.

Bonatti, E. and Crane, K. 1984. Oceanic fracture zones. Scientific American, 250: 5, 39-51.

OTTER. 1984. The Geology of the Oceanographer Transform: the ridge-transform intersection. Marine Geoph. Res., 6: 109-141.

Bonatti, E., 1985. Transition from a continental to an oceanic rift: punctiform initiation of sea floor spreading in the Red Sea. Nature, 316, 33-37.

Michael, P.J., and E. Bonatti, 1985. Peridotite composition from the North Atlantic: regional and tectonic variations and implications for partial melting. Earth Planet. Sci. Lett., 73, 91-104.

Michael, P. and Bonatti, E. 1985. Petrology of ultramafic rocks from sites 556, 558 and 560, DSDP leg 82 in the north Atlantic. Initial Reports DSDP, 82, 523-528.

Bonatti, E., 1986. Variabilita' nelle zone di accrescimiento di litosfera oceanica: rift "lenti" e "veloci", rift che si propagano, rift che si accavallano, rift che si esauriscono. Mem. Soc. Geol. It., 27, 23-34.

Bonatti, E., Ottonello, G. and Hamlyn, P.R., 1986. Peridotites from the island of Zabargad, (St. John's) Red Sea: Petrology and geochemistry. Jour. Geoph. Res., 91, 599-631.

Bonatti, E., P. Colantoni, F. Lucchini, P.L. Rossi, M. Taviani and J. White, 1986. Chemical and stable isotope aspects of the Nereus Deep (Red Sea) metal-enriched sedimentation. Mem. Soc. Geol. It., 27, 59-72.

OTTER. 1986. The geology of the Oceanographer Transform: the transform domain. Marine Geoph. Res., 7, 329-358.

MacDonald, K.C., D. Castillo, S. Miller, P.J. Fox, K. Kastens and E. Bonatti, 1986. Deep tow studies of the Vema fracture zone: Tectonics of a major slow slipping transform fault and its intersection with the Mid-Atlantic Ridge. Jour. Geophys. Res., 91, 3334-3354.

Bonatti, E., 1987. The rifting of continents, Scientific American, 256, 96-103.

Bonatti, E. and Seyler, M., 1987. Crustal underplating and evolution in the Red Sea rift, Jour. Geoph. Res., 92, 12083-12821.

Bonatti, E. and C.G.A. Harrison, 1988. Eruption styles of basalt in oceanic spreading ridges and seamounts: effects of magma temperature and viscosity, Jour. Geoph. Res., 93, B4, 2967-2980.

Brueckner, H., A. Zindler, E. Bonatti and M. Seyler, 1988. Zabargad and the pan-African Miocene isotopic evolution of the sub-Red Sea mantle, Tectonophysics, 150, 163-176.

Seyler, M. and E. Bonatti, 1988. Petrology of the gneiss/amphibolite lower crustal unit from Zabargad island, Red Sea. Tectonophysics, 150, 177-208.

Petrini, R., J.L. Loren, G. Ottonello, E. Bonatti and M. Seyler, 1988. Basaltic dykes from Zabargad island, Red Sea: petrology and geochemistry. Tectonophysics, 150, 229-298.

Bonatti, E., and P.J. Michael, 1988. Mantle Peridotites from Continental Rifts to Ocean Basins to Subduction Zones. Earth Planet. Sci. Lett., 91, 297-311.

Auzende, J.M., D. Bideau, E. Bonatti, M. Cannat, J. Honnorez, Y. Lagabrielle, J. Malavieille, V. Mamaloukis-Frangoulis, C. Mevel, 1989. Direct observation of a section through slow-spreading oceanic crust, Nature, 337, 726-729.